Coverage Metric for Acoustic Receiver Evaluation and Track Generation

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***Abstract*-Acoustic receiver track generation has been the subject of active research, both academic and operational, since at least 1946. In general, track generation algorithms operate by maximizing some measure of effectiveness or performance for a particular receiver in a particular environment. Current probability-based receiver performance measures are difficult to visualize, time consuming to calculate and are not easily subject to strict scientific analysis. Although great strides have been made in the ability to model and predict oceanography (temperature, salinity, currents, etc.) accurately, there exists the need to develop measures of receiver performance which more readily lend themselves to analysis of sensitivity to environmental variation or uncertainty.**

With the increasing dependence on optimization algorithms in acoustic receiver placement and track generation in the presence of variable or uncertain environments, the desire for a more environmentally-sensitive metric of acoustic receiver performance has arisen. A measure of performance based upon acoustic coverage area has shown promise as a basis for acoustic receiver utilization and optimized track generation applications and is presented here. Coverage can be defined as the areas throughout which a receiver has a sufficiently high signal-to-noise ratio or, alternatively, probability of making positive observations. For the purposes of determining optimal receiver placement and track generation the area of interest is divided into a sufficiently sampled grid of calculation points. Computing and compiling acoustic receiver coverage area information for grid points throughout the area of interest into an acoustic receiver coverage map gives immediate visual feedback on locations of optimal performance for a specific acoustic receiver in use in the current ocean environment. By making use of multiple calculation layers in an *N* × *2-D* fashion, acoustic coverage volumes can be constructed for the purposes of three dimensional receiver placement or track generation. The use of an acoustic coverage-based metric for optimal track generation is shown to compare favorably with current track optimizers which use cumulative probability measures of performance, offering faster calculation times and a stronger connection to the acoustic environment.

I. Motivation

Algorithms for optimizing the effective use of acoustic receivers require some metric to quantify the performance of the acoustic receiver at a location in the environment. In underwater acoustics the sonar equations provide a method of calculating an input signal-to-noise (SNR) ratio based upon the properties of the sonar equipment, the acoustic medium and the target object [1]. Because the SNR calculated by the sonar equations is dependent on source-receiver geometry and the operating characteristics of the source and receiver, a large number of values must be calculated in order to fully characterize a receiver's performance throughout the area of interest. This large amount of data makes it difficult to find ways to effectively present an overall picture of receiver performance. What is desired is a single valued quantity that represents the level of performance of a receiver at a location in an azimuthally and range dependent environment that is intuitive and easily visualized.

II. Method

For any given receiver, there will be some detection threshold which defines the lower limit of the input SNR for which an observation will occur at some user specified level of correctness [1]. The receiver's coverage is defined as the possible target locations in which the input SNR exceeds this detection threshold. Fig. 1 shows an example radial with the covered ranges indicated by shading. Unlike the definite range law, which assumes that there is some range *R* such that positive observations are only possible for $r < R$, coverage more realistically allows possible observations to occur for multiple regions in range. In many environments, e.g. those that exhibit strong convergence zones, this distinction can be a very important one. When desired, signal excess (SE) can be calculated via the sonar equation by subtracting the detection threshold from the signal to noise ratio. The covered regions are then easily defined as the regions bounded by the SE=0 threshold. Alternatively, coverage can be determined on the basis of the probability of detection (P_d). P_d can be calculated from SNR in any number of ways [2] [3] [4]. The threshold for coverage is then determined by the minimum required P_d

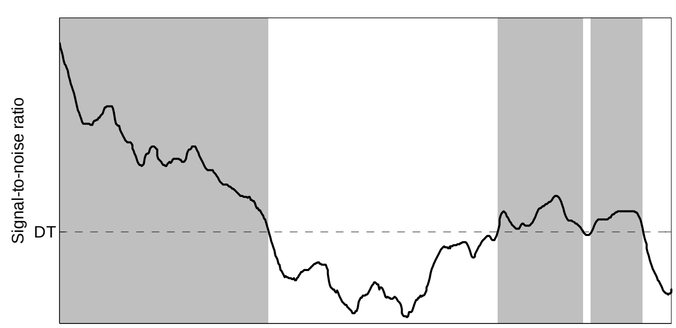

Figure 1. Plot of SNR vs. range for a single radial. The dotted line is the detection threshold and the gray shading indicates ranges for which the SNR exceeds the threshold.

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14. ABSTRACT

Acoustic receiver track generation has been the subject of active research, both academic and operational, since at least 1946. In general, track generation algorithms operate by maximizing some measure of effectiveness or performance for a particular receiver in a particular environment. Current probability-based receiver performance measures are difficult to visualize, time consuming to calculate and are not easily subject to strict scientific analysis. Although great strides have been made in the ability to model and predict oceanography (temperature, salinity, currents, etc.) accurately, there exists the need to develop measures of receiver performance which more readily lend themselves to analysis of sensitivity to environmental variation or uncertainty. With the increasing dependence on optimization algorithms in acoustic receiver placement and track generation in the presence of variable or uncertain environments, the desire for a more environmentally-sensitive metric of acoustic receiver performance has arisen. A measure of performance based upon acoustic coverage area has shown promise as a basis for acoustic receiver utilization and optimized track generation applications and is presented here. Coverage can be defined as the areas throughout which a receiver has a sufficiently high signal-tonoise ratio or, alternatively, probability of making positive observations. For the purposes of determining optimal receiver placement and track generation the area of interest is divided into a sufficiently sampled grid of calculation points. Computing and compiling acoustic receiver coverage area information for grid points throughout the area of interest into an acoustic receiver coverage map gives immediate visual feedback on locations of optimal performance for a specific acoustic receiver in use in the current ocean environment. By making use of multiple calculation layers in an N × 2-D fashion, acoustic coverage volumes can be constructed for the purposes of three dimensional receiver placement or track generation. The use of an acoustic coverage-based metric for optimal track generation is shown to compare favorably with current track optimizers which use cumulative probability measures of performance, offering faster calculation times and a stronger connection to the acoustic environment.

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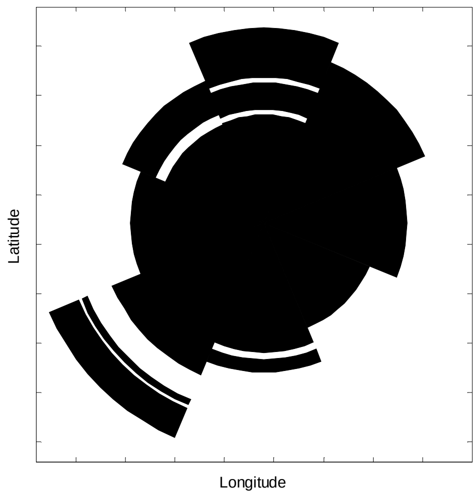

Figure 2. Coverage sector plot for a single location using eight radials. Filled sectors indicate areas where the SNR is above the detection threshold, therefore observations are possible in these areas.

to satisfy the experimental requirements. This flexibility in the choice of basis for the coverage calculations allows the metric to represent the strictest performance requirements of a definite detection or clean sweep search, or some relaxed level of certainty in observations.

In a typical acoustic receiver scenario calculations of the acoustic propagation will be made as a function of range in some number of radial directions (bearings) at gridded receiver locations within the area of interest. A polar plot of the covered region at a receiver position gives a visual representation of which ranges and at which bearings observations are possible. A coverage region for a single location in eight radial directions is shown in Fig. 2. By plotting this information at all locations in the grid the resulting coverage map will reveal regions of the area of interest where the acoustic receiver is exhibiting its best performance, i.e. the largest regions of possible positive observations, for the particular environment and operating parameters. In cases where the grid spacing is small, or the coverage regions are large, the coverage map may be difficult to interpret due to the excessive overlapping of coverage regions from one point to the next. A single valued coverage area surface for the grid can be created by calculating the total area of the covered region at each grid point. An example of a coverage map and the resulting coverage area surface for the Sea of Japan is shown in Fig. 3. The sound velocity in the water column was taken from the Modular Ocean Data Assimilation System (MODAS) model [5]. Bathymetry was extracted from the Digital Bathymetry Database – Variable Resolution (DBDBV) [6] and the geoacoustic sediment description was calculated using the Hamilton-Bachman method [7].

III. APPLICATIONS

It has been shown that the coverage metric can be used to give a visual representation of the extent of the region in which the acoustic receiver can make an observation through both individual coverage region plots, area wide coverage maps and the summarized coverage area surface plot.

One significant by-product of the coverage metric is an estimate of a location's level of *observability* to a receiver at a location. By examining any point in a coverage map plot, one could calculate the percentage of receiver locations in the grid whose coverage regions overlap that point. This observability measure gives an indication of the location's visibility to the receiver at that point. In Fig. 4 the observability data for the Sea of Japan is shown. Areas of high observability are clearly visible.

The coverage metric is also useful as a means of investigating the effect of environmental changes on receiver performance. Environmental snapshots in time can be

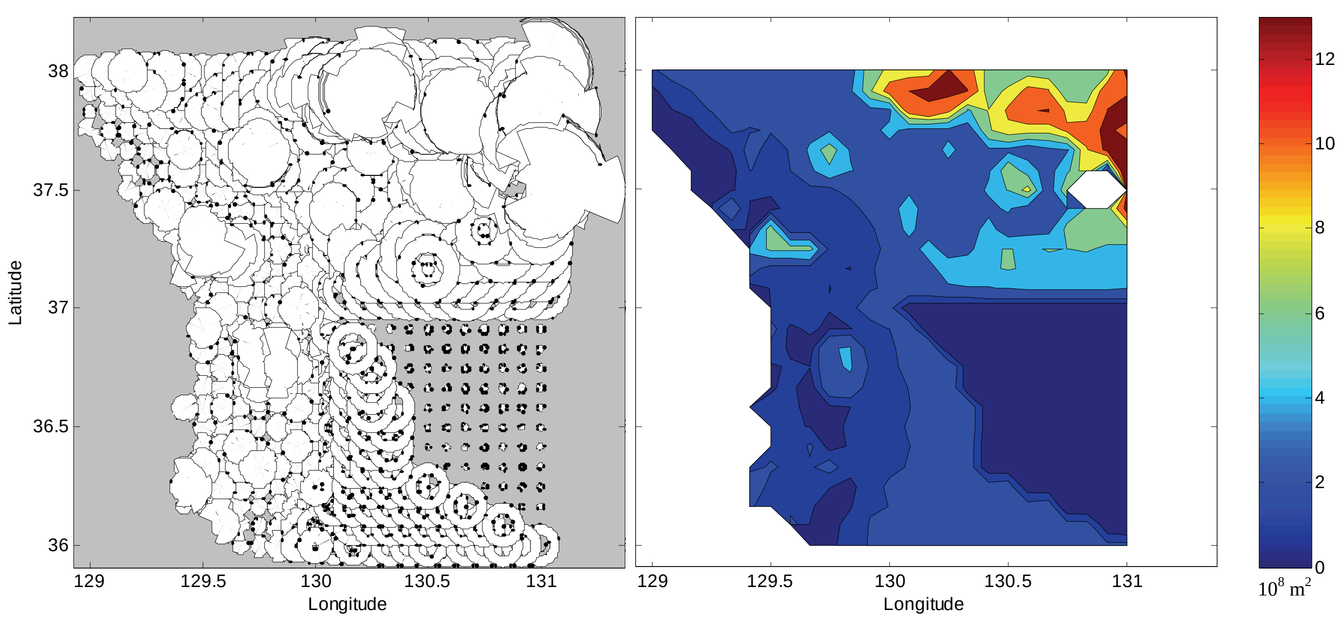

Figure 3. Left: An example of a coverage map from the Sea of Japan. Right: Coverage area surface plotted from the same SOJ data shown on the left.

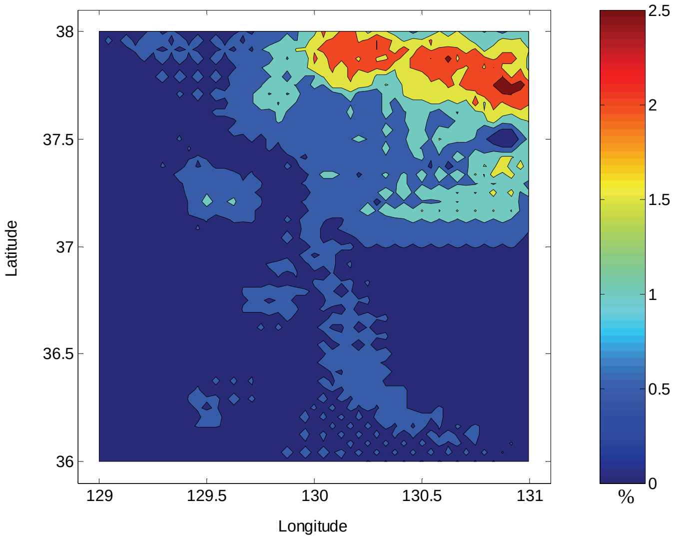

Figure 4. Observability plot of the Sea of Japan data. The color at each point represents the percentage of the entire are that achieves coverage of that point.

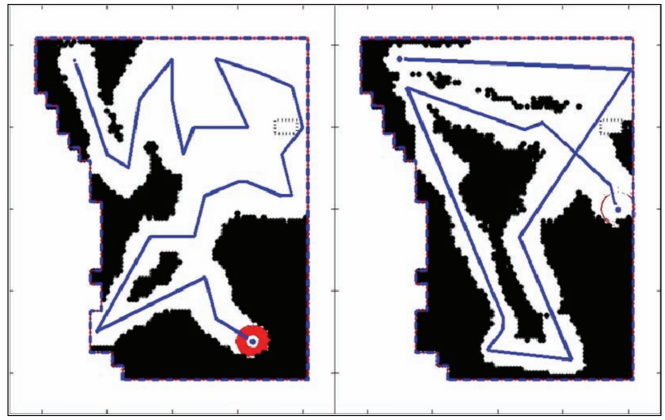

Figure 5. Comparison of optimal search tracks generated by a simple TSP algorithm visiting the largest coverage areas (left) and by the more sophisticated and computationally intensive genetic algorithm in ORP (right). Both tracks observed roughly the same number of objects, but the path on the left took ⅓ of the CPU time to generate than the one on the right.

analyzed with coverage to create a visual representation of the changes in receiver performance in time due to changes in the environment. Monte Carlo simulations of uncertain environments could likewise be analyzed for an indication of how uncertainty in the environment affects receiver performance. Recent work has been done using the coverage metric as an indicator for the range dependence of an ocean environment in order to reduce acoustic estimation time [8].

The coverage metric has been used as the basis of receiver placement and optimal track algorithms. In particular, simple track optimization methods have been applied to coverage metric data with promising success. A simplistic scheme in which the grid points with the largest coverage areas are connected with a path of minimum length has performed as well as much more complicated and time consuming algorithms in generating optimized receiver tracks. Fig. 5 shows the results from one such comparison. In this test using the Sea of Japan data, the twenty-five grid points with the largest coverage areas were connected with a path of minimum length using a simple traveling salesman problem (TSP) routine [9]. The same data was given to a modified version of David H. Wagner & Associate's Operational Route Planner (ORP) to use its sophisticated genetic algorithm [10] to optimize a track of the same length that maximizes the total coverage area. The resulting tracks from both methods were evaluated against a uniform field of stationary objects. A receiver executing the ORP generated path observed 55.79% of the objects while the TSP generated path resulted in 56.37% object observation in approximately ⅓ the CPU time needed by ORP. The mathematically simple nature of the coverage metric calculation and quick evaluation against possible observation locations allows simple tools such as the TSP scheme described above to quickly generate optimized tracks that equal the performance of more complicated and time consuming methods.

For experiments where multiple receivers are candidates for use, a coverage map or coverage area surface can be generated for each receiver type. Locations throughout the area of interest can then be allocated to the receiver(s) that achieves the greatest coverage area there. In this way, combinations of different receivers can be optimized to maximize the total area covered throughout the environment.

While the previous discussion has been limited to a single depth, there is nothing restricting the extension of the coverage metric into the third dimension. Multiple possible observation depths would be easily handled in an $N \times 2\text{-}D$ fashion. For each observation depth, the coverage region and area would be calculated as described, regions being extruded in depth to create volumetric regions. These volumetric regions would define the volumes within which observations would occur. Coverage areas become coverage volumes in the 3-D metric.

IV. Future

All of the current applications of the described coverage metric are in evaluation and optimization of the performance of acoustic receivers in underwater environments. Because of the generalized nature the detection threshold concept, the coverage metric can be used in a wide range of situations involving any observation system functioning in any environment. Future work should extend the application of the techniques described here to other acoustic and non-acoustic receivers.

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